

Review

# Probiotics, Non-Dairy Prebiotics and Postbiotics in Nutrition

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**Abstract:** The review covers achievements and developments in the field of probiosis and prebiosis originating from sources other than dairy sources, mainly from plant material like cereals. The actual definitions of probiotic microorganisms, prebiotic, and postbiotic compounds and functional food are discussed. The presentation takes into account the relations between selected food components and their effect on probiotic bacteria, as well as effects on some health issues in humans. The review also focuses on the preservation of cereals using probiotic bacteria, adverse effects of probiotics and prebiotics, and novel possibilities for using probiotic bacteria in the food industry.

**Keywords:** consumer preferences; functional food; nutraceuticals; probiosis; taste

## 1. Introduction

Food that improves human's life and cures diseases is a concept that has many faces. One of the most complicated loops is: nutrient (prebiotic), which is treated by specific bacteria (probiotic) and products (postbiotic) that are biologically active. The probiotics, their nutrients–prebiotics and derived from the latter postbiotics attract considerable attention of clinicians, microbiologists, dieticians and nutritionists as well as food technologists and agriculture. A number of recent contributions covers problems of probiotics and prebiotics in general [1,2], functional, healthy foods and beverages [3–8], effects of processing upon some sources [9], consumer preferences [10,11], mathematical models for probiotic fermentation [12] and curing infectious diarrhoea [13]. They perfectly underline the significance of the problem. This review presents novelties in the field of probiotics and then focuses on cereals—a relatively new type of prebiotics. As a main food component, cereals contain a considerable amount of insoluble and soluble fibre utilised as nutrients by probiotics and deliver several interesting postbiotics. Cereal prebiotics are also a healthy alternative for humans who do not tolerate dairy products. However, there is also a group of consumers who do not tolerate cereals. Therefore, in this review, prebiotics originating from other plants are briefly mentioned.

## 2. Probiotics

In 2013, a panel of experts slightly modified the World Health Organisation/Food and Agriculture Organisation (WHO/FAO) definition of probiotics into “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host” [14]. Currently, the research in this field focuses mainly on the gastrointestinal (GI) tract. However, bacteria also colonise the skin, urogenital tract, and airways. New microbial niches have been discovered in, thus, far considered sterile organs and tissues, such as the placenta, amniotic fluid, mammary gland and human milk. Very sensitive genetic techniques have confirmed the presence of microbes in the blood. They are *Proteobacteria*

phylum (more than 80%) but also from *Actinobacteria*, *Firmicutes*, and *Bacteroidetes* [15,16]. These findings changed the frontiers of in vivo probiotics research [16–20].

*Lactobacillus* species are the most commonly utilised fermentative bacteria [21,22]. Although suitability of lactic acid bacteria for fermentation of maize and amaranth has been reported [23], some *Lactobacilli*, for instance, *Lactobacillus acidophilus*, poorly grow in cereal products. Therefore, in such applications, it is combined with *Rhizopus oryzae* [24]. Among fermentative bacteria, these assigned to the genus *Weissella* of the group of lactic acid bacteria, are particularly interesting. *Weissella* spp. occur in a wide range of habitats, e.g., on the skin and in the milk and faeces of animals, saliva, breast milk, human faeces and vaginas, plants and vegetables as well as a variety of fermented foods, such as European sourdoughs, Asian and African traditional fermented foods. These microorganisms are receiving attention as potential probiotics delivering novel non-digestible oligosaccharides and extracellular polysaccharides, mainly dextran. Potentially, as bioactive compounds, they might be useful in a wide range of industrial applications, predominantly for bakeries and production of cereal-based fermented functional beverages [25].

Generally, microbes which are recognised as beneficial are called probiotic bacteria. The positive effect of those bacteria is local and distant, involving the whole body.

### 3. Modern Probiosis

A considerable number of clinical studies confirm the positive effect of probiotics and prebiotics in maintaining health and therapy. They cure diseases of some organs or alleviate their symptoms, for instance irritable bowel syndrome, *Helicobacter pylori* gastritis, inflammatory bowel disease, diarrhoea, non-alcoholic fatty liver disease, and atopic dermatitis. Clinical studies suggest the effectiveness of probiotics in the treatment of diseases involving the whole body, such as obesity, insulin resistance syndrome, and type 2 diabetes [26,27]. Probiotics also increase body immunity (immunomodulation). Benefits of the prophylactic use of probiotics in different types of cancer and cancer-associated side effects have also been reported [28]. The influence of probiotics on allergy remains unclear. Long-time follow-up of infants fed with cereals containing probiotic *L. paracasei* spp. *paracasei* F19 and a control group fed with probiotic free cereals showed no difference in the allergy risk in both groups [29,30]. A supplementation of cereals with probiotics had no effect on caries in children [31].

Maintaining the skin in good condition with relevant probiotic bacteria appears very promising. Skin bacteria prevent skin irritation, including sun irritation, topical allergy, inflammation, acne, dandruff, alopecia, psoriasis and likely skin cancer [32–34]. Following these results, the cosmetic industry introduced a wide range of topical products enriched with probiotics and more commonly with prebiotics specific for beneficial skin bacteria. Such an approach to curing vagina, urinary tract, and respiratory tree disorders with their bacterial microflora is less common.

A personalised microbiome is a novel emerging concept [35]. Such an approach is based on personalised diets, individual-specifically composed. Cereals as common components of a diet, are stable in commercial and home-made processing and are very promising.

### 4. Prebiotics, Functional Food, Bioactive Ingredients and Nutraceuticals

The old but still valid FAO definition of prebiotics states that ‘a prebiotic is a non-viable (in opposition to probiotics) food component that confers a health benefit on the host associated with modulation of the microbiota’ [36]. However, in December 2016, experts of the International Scientific Association for Probiotics and Prebiotics (ISAPP) recommended the new definition of a prebiotic, ‘a substrate that is selectively utilised by host microorganisms conferring a health benefit’. Thus, a prebiotic may not be a food component. This new definition expands to a wide range of inorganic and organic substances stimulating microorganisms in all niches of the body and not only in the GI tract. It has an essential implication for microbiomes outside of the gastrointestinal tract, especially in the skin, urinary tract, vagina, and so on [37]. In addition, the definition requires documented beneficial health effects of potential prebiotics.

However, that definition evokes some doubts as a number of medications clearly fit this definition. Some antibiotics are utilised by pathogenic bacteria, and the expected effect of those drugs is beneficial for health. Should they be recognised as prebiotics?

These definitions leave apart biological processing involving probiotic bacteria outside the human/animal body (in vitro). Likely, compounds processed outside living organisms using probiotic bacteria, and ingested/used by humans/animals with beneficial effect, should also be accounted for prebiotics.

There is neither a regulation nor any obligatory definition for healthy food, functional food, nutraceuticals, or nutraceutical supplements. Depending on countries, companies, and scientific and consumer societies, various definitions are followed. For instance, functional food is most commonly defined as a food improving health, and nutraceuticals are described as special, pharmaceutical-grade, and standardised nutrients. Another definition states that functional food contains bioactive ingredients, which can be chemical compounds, and the others include also probiotic bacteria. The latter approach implies four main active compounds of functional food: (i) probiotic bacteria, (ii) substrates for their growth (clear prebiotics), (iii) substrates for bacteria metabolism, resulting in biologically active compounds beneficial for the host (could also be called prebiotics), and (iv) biologically active chemical compounds, called recently postbiotics.

#### 4.1. Prebiotic Compounds

Formerly, prebiotics were considered as non-digestible dietary fibre that exert some biological effects involving selective stimulation of growth and bioactivity of beneficial microorganisms either present or therapeutically introduced to the intestine. Probiotics in functional food reside mostly in dairy products. Nevertheless, there is a need for the development of non-dairy probiotics and non-fibre prebiotics.

According to the new definition of prebiotics, polyphenols and fatty acids could be included in this group together with some peptides catabolised by bacteria into active ingredients. Even inorganic materials (i.e., micronutrients necessary for the development of bacteria) used externally and internally could be considered as prebiotics.

#### 4.2. Cereals and Their Derivatives as Prebiotics

Cereals constitute a relatively new group of prebiotics. The most common prebiotics are identified as vegetables and fruit fibres, and dairy products act as probiotic carriers [38]. Grain-based prebiotics, which are a part of a natural everyday diet for most of the human population, are very promising. Cereals are rich in insoluble fibre, soluble fibre ( $\beta$ -glucans and arabinoxylan), galactooligosaccharides (GOSs), fructooligosaccharides (FOSs) and resistant starch [39]. Whole grains are also sources of many phytochemicals, including phytoestrogens, phenolic compounds, antioxidants, phytic acid, and sterols [21,40]. It was shown [41–43] that dietary fibre prepared from maize starch are well tolerated by the human organism. They activate the growth of *Bacterioidetes* and *Actinobacteria* inhibiting simultaneously the growth of *Firmicutes* responsible for obesity, similarly, they act also as potato dextrins [44,45].

Products of the lactic acid fermentation of cereals and their derivatives are safe, they enhance the nutritional value of cereals, either improve or change their taste and help to preserve the food. This kind of processing, very common in Asia and Africa is employed in manufacturing beverages, gruels, pancakes, and porridge from fermented rice, sorghum, maize, millet, non-cereal cassava, and wild legume seeds [46]. That food has relatively long shelf life under ambient temperature, and is widely accepted by consumers including expectant/breastfeeding mothers, and sick and recovering persons [47]. Also, in the Western dietary culture, cereals either fermented in vitro or treated by bacteria in vivo used to be added to a variety of functional foods. Frequently, it is a rediscovery of procedures known for centuries, for instance, kvass (a soft drink) containing living bacteria.

Below, the novel impact of prebiotics, especially cereals and their modifications, on probiosis and health of the main body systems will be briefly discussed.

#### 4.2.1. Gastrointestinal Tract

Numerous studies indicated that in contrast to conventional dairy products, cereal products may offer healthier options for the delivery of probiotics. Probiotics are common in dairy products, but cereals are more commonly accepted and consumed [48]. Required cold storage and transportation limit the use of dairy products. A dry food matrix is also a good carrier for probiotic bacteria. The intake of the probiotic *Bifidobacterium lactis* Bb-12 in an oat-based cereal bar resulted in colonisation in five of the nine subjects, lasting one week after cessation of *B. lactis* Bb-12 feeding [49]. Fermented oat milk-like beverages could be a compromise between cereal and milk diets. It is rich in probiotic bacteria and has a reasonable ratio of oat  $\beta$ -glucans [50]. Cereal  $\beta$ -glucans improve probiotic-enterocyte adhesion. It could inhibit intestinal colonisation by unfavourable bacteria and, therefore, promote the settlement of probiotic strain [51].

The feeding of a cereal containing *Streptococcus thermophilus*, *B. lactis*, *L. acidophilus*, and zinc reduced the severity and duration of acute gastroenteritis in young children. However, whether this combination is better than either the addition of probiotics or zinc alone is yet to be determined [52].

Cereal-based fermented food products should be taken into account as a promising source of new probiotics. In Nigerian traditional fermented food, *Pichia kluyveri* LKC17, *Issatchenkia orientalis* OSL11, *Pichia kudriavzevii* OG32, *Pichia kudriavzevii* ROM11, and *Candida tropicalis* BOM21 were found. They are potentially promising new probiotic strains [53].

#### 4.2.2. Skin

In cosmetology, prebiotics, such as FOSs (mainly extracted from fruits and vegetables), mannoooligosaccharides, synthetic or lactose-derived lactulose and mainly cereal  $\beta$ -glucans are widely used [54,55]. These prebiotics restore and stimulate the skin beneficial probiotic bacteria and fungi. Moreover, balancing skin pH with prebiotics in cosmetics improves the hydration of surface layers of the skin and normalises its keratinisation and exfoliation. Oligosaccharide probiotics of hairy skin limit the growth of *Malassezia furfur* responsible for dandruff and maintain the production of sebum. Possibly a stimulation of dermatophytes and blastomycetes is involved. “Fermented” cosmetics, naturally processed synbiotics, mainly from Asia, design new trends in cosmetology. The technology of their production is different, but the final effect resembles that of the use of extracted compounds.

#### 4.2.3. Urogenital Tract

Little is known about the role of prebiotics in maintaining vaginal microflora although vaginal and women lower urinary tract infections are extremely common. Only a few older studies about the positive effects of FOSs and GOSs in vaginal treatment are available [56]. The urogenital tract could be colonised by bacteria administered orally with or without prebiotics [57]. Gut microflora interacts with the urogenital tract, the so-called gut-urogenital axis. It is known that proper gut microbiome stimulated by oral delivery of prebiotics reduces the level of some uremic nephrovascular toxins in patients with chronic kidney diseases. Gut dysbiosis is responsible for the progression of kidney disease [58]. It leads to new therapeutic opportunities for prebiotic and probiotic supplementation preventing kidney diseases and limiting their progress.

Prebiotics and probiotics could also be helpful in men during reproduction. Half-year treatment with orally delivered synbiotic composition of lactic acid bacteria (LAB) and arabinogalactan, FOS and L-glutamine increases the volume of the ejaculate and the quality/quantity of spermatozoa in patients suffering from idiopathic oligoasthenoteratospermia [59]. Likely, such an effect could also be seen in healthy men.

#### 4.2.4. Metabolic Diseases

The dysbiotic gut is linked to obesity, type 1 and type 2 diabetes, and non-alcoholic fatty liver disease. The transfer of gut microflora from obese animals induces their metabolic disease and obesity in followed animals. Conversely, the transfer of pathogen-free microbiota from lean healthy human donors to patients with metabolic disease can increase the sensitivity to insulin [60].

A diet based on rich in prebiotic-fermentable fibre,  $\beta$ -glucans, and plant polyphenols whole-grain cereals, vegetables, and legumes significantly reduces glycaemia, HbA1c, and insulinaemia. It also lowers blood cholesterol and low-density lipoprotein cholesterol. The ratio of low-density lipoprotein cholesterol/high-density lipoprotein cholesterol, triglycerides, blood urea, microalbuminuria, body weight, and body fat in type 2 diabetes patients also decrease [61].

Excessive consumption of red meat increases the risk of cardiovascular diseases. Intestinal microbiota metabolise metabolites of choline, phosphatidylcholine, and L-carnitine into proatherogenic trimethylamine-N-oxide (TMAO) [62].

### 5. New-Quality—Processing of Foodstuff by Probiotic Bacteria In Vitro

Malting of cereal grains and probiotic lactic acid fermentation of plant-based media increase the nutritional quality of final products. Fermentation is one of the oldest technologies in food processing. LAB are commonly used for the fermentation of a large variety of foods. Most of the commercialised lactic acid fermented products originate from dairy sources. Although they are good matrices for probiotics, their consumption is limited because of growing both veganism and the number of lactose-intolerant individuals and propagation of various restricted diets. Thus, the development of non-dairy probiotic products, such as fruits, vegetables, and cereals as food matrices, is very promising [63]. Particularly, products from cereals fermented with probiotic bacteria pay considerable attention as a cheap way to nutritionally rich food either with or without probiotic bacteria. The most common fermented products of grain origin are presented in Table 1. In many cultures, including Western countries, many fermented products are heated and cooked prior to consumption. These procedures kill probiotic microorganisms [9].

**Table 1.** Products from fermented cereals.

Dish	Fermented Source	Country	Fermenting Species
<b>Beverages</b>			
Non-alcoholic			
Amazake	rice	Japan	<i>Aspergillus</i> spp.
Boza	various cereals	Balkan countries	<i>Leuconostoc</i> spp., <i>Lactobacillus</i> spp.
Bhaati jaanr	rice	Himalaya countries	<i>Saccharomyces</i> spp. <i>Saccharomycopsis</i> <i>fibuligera</i> , <i>Rhizopus</i> spp.
Bushera	sorghum, millet	Central Africa	<i>Lactobacillus</i> spp. <i>Streptococcus</i> spp.
Haria	rice	India	<i>Bifidobacterium</i> , <i>Saccharomyces</i> spp.
Koko	pearl millet	Ghana	<i>Weissella confusa</i> , <i>Lactobacillus fermentum</i>
Kvass	rye bread, rye and barley malt/flour	Russia, Ukraine	<i>Lactobacillus casei</i> , <i>Lactobacillus mesenteroides</i> , <i>Saccharomyces</i> spp.
Mahewu	maize	Central Africa	Lactate producing bacteria
Malta	barley, hops	Denmark, Germany, Caribbean	<i>Saccharomyces</i> spp.

Table 1. Cont.

Dish	Fermented Source	Country	Fermenting Species
<b>Beverages</b>			
Mangisi	millet	Zimbabwe	yeast and mould
Podpiwek	grain coffee, hops	Poland, Lithuania	<i>Sacharomyces cerevisia</i> <i>Lactococcus lactis</i> , <i>Lactobacilli alimentarium</i> , <i>casei</i> and <i>delbruekii</i> , <i>Enterococcus</i> , <i>Lactol</i> <i>Saccharomyces</i> spp.
Pozol	maize	Mexico	
Supermalt	malt	Worldwide	
Tongwa	maize	Central Africa	<i>Lactobacilli</i> , <i>Saccharomyces</i> spp.
<b>Low-alcoholic beverages</b>			
Chhang	rice, barley, millet	Tybet	<i>Lactobacillus</i> spp., <i>Saccharomyces</i> spp.
Malt beer	barley malt syrup, hops	Worldwide	yeast
<b>Average-alcoholic beverages</b>			
Malt beer	barley malt syrup, hops	Worldwide	yeast
Malt liquor		Worldwide	<i>Saccharomyces</i> spp.
<b>High-alcoholic beverages</b>			
Malt whisky	malted barley		<i>Saccharomyces</i> spp.
Sake	rice	Japan	<i>Aspergillus oryzae</i> + yeast
Spiritus (vodka)	rye, barley, maize	Worldwide	<i>Saccharomyces</i> spp.
Tesgiüino	Sprouted corn	Mexico	yeast
<b>Fermented food <sup>a</sup></b>			
Appam	rice batter + coconut milk	India, Sri Lanka	
Bread	cereal flours	Worldwide	
Brem	rice	Indonesia	
Chakuli pitha	rice and black gram	India	
Dhokla	rice	India	
Dosa	rice	India	
Enduri pita	rice and black gram	India	
Injera	a sourdough-risen flatbread made out of teff flour	Ethiopia	
Kenkey	White maize grits	Africa	
Khanom chin	rice noodles	Thailand	
Mageu	porridge	South Africa	
Ogi	cereal pudding	Nigeria	
Pesaha appam	Fermented bread	India	
Puto	Rice cake	Philippines	
Sowan	starch remaining on the inner husks of oats after milling	Scotland	
Tapai	Rice or starch	Southeast Asia	
Zhur	Rye flour	Poland	

<sup>a</sup> Various fermenting species are in use.

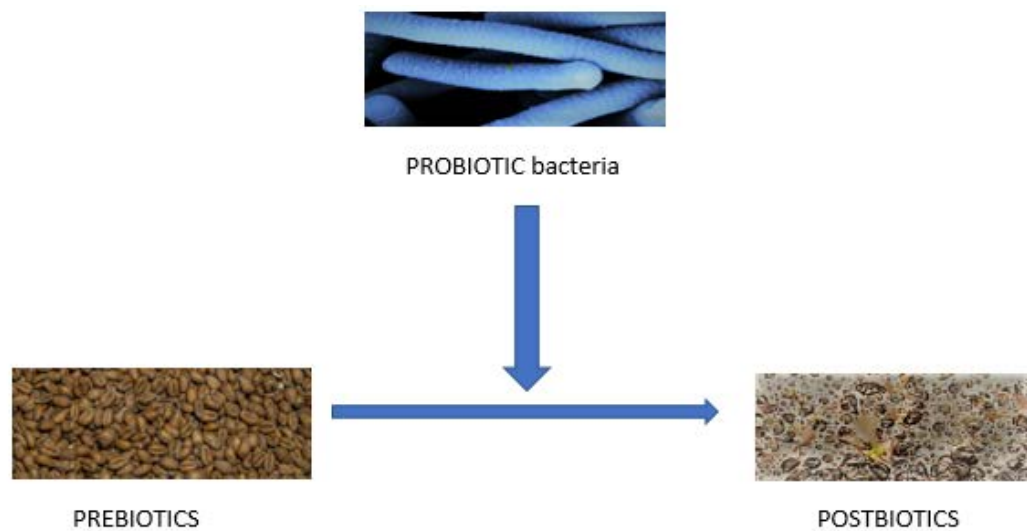
Fermentation of cereals provides products of longer shelf life, less allergy and higher nutritional value (vitamins and essential amino acids), and appreciated organoleptic properties.

## 6. Postbiotics

Recently a new term “postbiotic” was introduced [64]. It is defined as a combination of all bioactive components generated by bacteria, for instance, on fermentation, which acts beneficially when introduced into the human organism (Figure 1). Postbiotics can include bacterial lysates with cell surface proteins, bacterial enzymes and peptides, metabolites produced by bacteria such as teichoic acids, peptidoglycan-derived neuropeptides, polysaccharides, and lower organic acids, for instance, lactic acid. Postbiotics can stimulate the immunological system, likely involving bowel



and intestine developing anti-inflammatory, immunomodulatory, anti-obesogenic, antihypertensive, anti-proliferative, antioxidative, and hypocholesterolemic activity.



**Figure 1.** Relation between prebiotics (grains), probiotics bacteria, and postbiotics (selected fermented products and selected bacteria residue).

In the food, as well medical technology, fermentation is the most common source of postbiotics.

An increase in the B vitamins content in cereal grains presents another spectacular example of postbiotic fermentation. Grains contain considerable levels of the B group vitamins. Frequently, these vitamins are removed upon milling or destroyed on thermal processing. Fermentation of cereals, as well as their pre-treatment with LAB, supports bacterial synthesis elevating the content of vitamins B1, B2, B3, B9, B11, and B12. Potentially it is a strategy for increasing the B vitamin content in cereal-based products [65,66].

LAB fermentation of grains significantly enhanced levels of total lysine, protein fractions, sugars, soluble dietary fibre in vitro, and bioavailability of Ca, Fe and Zn. Also, LAB fermentation of wheat could provide antihypertensive angiotensin I converting enzyme (ACE)-inhibitory peptides and  $\alpha$ -aminobutyric acid (GABA) and antioxidant peptides [67,68]. There are attempts to use enzymes instead of probiotic bacteria to get more specific effects. Purified phytases from *Bifidobacterium longum* spp. *infantis* and *Bifidobacterium pseudocatenulatum* reduced the content of phytates in cereal mixtures and led to increased levels of myo-inositol triphosphate. They also increased the solubility of zinc [69].

The new approach is not only connected with enriching food in postbiotics, but also with the deletion of some potentially harmful components of the food during probiotic-induced fermentation. It was found that fermentation with probiotic bacteria *L. paracasei* CBA L74 decreases the concentration of harmful gliadin peptides in celiac patients [70]. The mechanism involves LAB proline-specific peptidase systems. As  $\alpha$ -gliadins in gluten are rich in proline, they are hindered from hydrolysis by enzymes of the GI tract. A joint action of peptidase from LAB strains and GI enzymes could offer a solution for celiac patients. A recently exhausted review on the potential application of postbiotics in early life nutrition and beyond was published [71]. That review considers postbiotics as an efficient and safe way of improving health conditions, is also suitable as a more safe alternative in case of immunocompromised or severely ill new-borns.

#### 6.1. Better Taste—An Extension to the “Beneficial” Action of Probiotics

Flavour is one of the most important organoleptic property of food. Sourdough fermentations employ complex and diverse microflora consisting of yeasts and LAB, mainly *Lactobacillus*. These complex fermentations add characteristic sensory attributes to the baked bread. Because probiotic microorganisms are killed upon baking, bread is not symbiotic [4]. Therefore, the fermented

unbaked/uncooked cereals are the most interesting for their unique sour with mild sweet and malty taste.

The industry seems to be focused on cereal beverages. Fermentation of malt, barley, and barley-malt media by potentially probiotic *L. paracasei* and *L. delbrueckii* resulted in better conservation of processed beverages [72]. In Eastern Europe, soft drinks and sour rye soups based on fermented bread, wheat or cereals are common for centuries. Japanese cuisine is particularly rich in fermented foods. It includes fermented fruits and vegetables, fish, soy beans, and other sources. The common Japanese soup, miso is based on soy beans fermented with koji malt rich in *Aspergillus oryzae*. The same microorganism is utilised in the production of traditional soy sauce (shoyu). Soybean sprouts are fermented with *Bacillus subtilis* into traditional Japanese appetizer – natto. A traditional fermented dish involves pickles, carrots, daikon, turnip, eggplant, and rice bran all pickled together in vinegar. Umeboshi is prepared from Japanese plums through lactic acid fermentation [73,74]. In China, particularly in Taiwan, stinky tofu made by fermentation chiefly involves LAB, although stinky tofu fermentation does not have a fixed formula and wide regional and individual variations exist in its manufacture and preparation [75]. *Lactobacillus* spp. is specially blended with vegetables, chiefly a Peking cabbage, into a traditional Korean dish called kimchi. Also, Indian regional cuisines are rich in fermented foods [39].

These new tastes are based chiefly on well-known fermentative bacteria strains such as *Bifidobacterium breve*, although new or unusual probiotic microorganisms like yeast are used [76]. The probiotic yeast *Pichia kudriavzevii* OG32 improved the sensory and some functional properties, such as an increase in viscosity [77].

## 6.2. Probiotics in the Grain Preservation

In the agricultural industry, probiotic microorganisms hinder the colonisation of sorghum grains and peanuts [78]. For instance, LAB reduces the content of phytate, an anti-nutrient in cereals and inhibits moulding [79,80]. Also, *Saccharomyces cerevisiae* var. *boulardii*, *S. cerevisiae* UFMG 905, and *L. delbrueckii* UFV H2b20 reduce aflatoxin and spore production by *Aspergillus parasiticus* IMI 242695 in peanuts [81]. What is more, fermented food contains some antimicrobial agents, mostly bacteriocins. The subject is still explored as interesting for the agricultural industry.

## 7. The Recognition and Uptake of Prebiotics among Consumers

Modern consumers pay considerable attention to their lifestyle. It generates increased demand for food promoting health and wellness through busting immune system providing a reduced risk of certain cancers and cardiovascular diseases, balanced metabolism and proper weight, improved eyesight, memory and physical efficiency [82]. Motivations depend on age and gender. Young men, as opposed to women and older men, pay less attention to the consequences of consuming functional food [83]. Other study indicates that only 20% and 7% of patients could correctly define probiotics and prebiotics, respectively. More patients consumed probiotics (53%) than prebiotics (38%). Among the most frequently consumed probiotic and prebiotic products were yogurts (72%) and cereals/granola bars (55%). Patients considered probiotics and prebiotics most beneficial for 'digestion or gut health', but the most common reason to consume these products was 'to taste or try' (36% and 43%, respectively) [84].

In Europe, a high percentage of the population consumes functional food. Women, older people (35–60 years), and those with university educations pay attention to natural and eco products, nutritional value, freshness, food safety, and quality guarantees. Fibre-rich breads/cookies were consumed, first of all, by individuals with medium education. Females more often consumed soy milk, fibre-rich bread/cookies and teas; males and females with a medium income preferred breakfast cereal. Obese individuals less likely consumed breakfast cereals and fibre-rich bread/cookies [85]. Older persons commonly consumed functional foods such as yogurts with probiotics (56.0%), eggs with omega-3



fatty acids (37.0%), and bread with fibre (35.5%). Young consumers are more open to high-technology food processing.

## 8. Limitations of Functional Food

Several papers document benefits from the use of probiotics and prebiotics and their generally positive role. However, recent, extended metagenomic study of the human GI microbiome indicates that person-, region-, and strain-specific mucosal colonisation by supplemented bacteria is not obvious. Probiotics have a transient and individualised impact on the mucosal microbiome [86]. After antibiotic therapy, the colonisation of the GI tract by exogenous probiotics is markedly delayed and persistently incomplete. It appears that the best way to promote the long-term improvement of GI microflora is the opposite way of supplementation, that is, faecal microbiome transplantation [87]. However, this kind of therapy seems to be much less acceptable than oral supplementation. Enhancing the number of supplemented bacteria is not the best solution. An excess of probiotic supplementation is unfavourable. An excess of LAB can result in some local problems such as belching, bloating, discomfort or even stomach ache as well as rectal sensations, including gases and loose stools [88]. Likely, such effects could also be distant and generally associated with lactic acidosis. This metabolic disturbance is connected with brain foginess, a complex of cognitive dysfunction involving memory problems, lack of mental clarity, poor concentration, and mental fatigue [89]. Recent data indicate that *Bifidobacterium* might also have an adverse effect on glucose metabolism by reducing butyrate-producing microbes [90].

It should be taken into account that probiotics are sold as medications and/or food supplements, and they are usually well defined and their dosage is known. Prebiotics are a common component of food and rarely a partially purified supplements. So, the knowledge of the adverse effects of overdosing of prebiotics is very limited. This subject is ignored even in serious well-composed scientific studies, such as the effects of formulae supplemented with prebiotics upon the health of infants [91]. However, some reports demonstrate an adverse effect. It could be related to an overgrowth of probiotic bacteria induced by excessive supplementation of prebiotics [92]. Moreover, also straight effects can be observed. For instance, an excess of inulin aggravates atherosclerosis in hypercholesterolemic mice and supplementation with fibre could limit access to microelements [93,94] should be taken under consideration.

### *In Summary*

In modern pre- and pro-biosis, non-dairy products did not meet yet sufficient attention. Particularly, cereals offer new intriguing prospects. They are commonly consumed all over the World for their availability and nutritional value. Recent research points to them as prebiotics. Among others, prebiotic of non-dairy origin are efficient in preventing atherosclerotic disease and cardiac incidences, prevents intestinal disorders, including cancer, reduces high blood sugar, and improves the course of some metabolic diseases. A variety of cereals, specific bacteria used for fermentation, and finally thousands of mid- and final biologically active products called postbiotics offer a huge potential of this part of nutrition and stimulate future scientific research in this area.

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